or boats requiring a shallow open scale, it is equally suitable for deep-water scales up to 1,000 fathoms, and when fitted to a deep-water recording set, can be used up to 6,000 fathoms.

For use in surveying boats a scale of 0 to 90 feet/fathoms has been adopted, though for special purposes the large scale of 0 to 40 feet is also supplied.

The accompanying photograph illustrates the "Universal" recorder. The glass window and the end of the rotating arm carrying the stylus are clearly visible, as also the actuating switch in the top right-hand corner for changing the scale from fathoms to fact.

Different patterns of recorder *M.S. XII* may be delivered; present prices of the various makes are as follows:

M.S. XII.	
One scale only, *no* phasing	£300 0 0
M.S. XIIB.	
One scale only, *with* phasing	£320 0 0
M.S. XIIC.	
Two speed gear (ratio to be decided by customer) *no* phasing	£330 0 0
M.S. XIID.	
Two scales (ratio to be decided by customer) *with* phasing	£360 0 0
M.S. XIIE.	
Extra powerful oscillators, suitable for greater depths or greater speeds of ships	£400 0 0

A MAGNETOSTRICTION ECHO DEPTH-RECORDER

(British Patent N° 375375)

by

A. B. WOOD, D. Sc., F. D. SMITH, D. Sc., Associate Member,
and J. A. McGEACHY, B. Sc.

(Reproduced from *The Journal of the Institution of Electrical Engineers* - Vol. 76, No. 461. London, May 1935).

I. — INTRODUCTION.

At the present time there are in existence several types of marine echo-sounding devices in regular use. Some of these may be described more particularly as depth *indicators*, whilst one or two not only give isolated indications of the depth of the sea but also provide a more or less continuous record of the sea-bed.

Echo-sounding devices may conveniently be divided into two main classes:

a) Low-frequency (sonic) systems, and

b) High-frequency (supersonic) systems.

Of these, the British Admiralty system is of the low-frequency type. Recently this system was fitted with an electrochemical recorder, (1) similar in principle to that described in the present paper but differing in mechanical features. The only high-frequency system which has hitherto attained commercial importance uses the supersonic vibrations of a quartz piezo-electric oscillator. This system, devised by Prof. Langevin and M. Chilowsky, has been developed commercially in this country by the Marconi Sounding Device Company. These two echo depth-sounding systems are now sufficiently well-known to render further detailed reference to them unnecessary.

The present paper is concerned with a description of an entirely new type of high-frequency echo depth-recorder which possesses important advantages over the two types mentioned above.

It is desirable to explain that this new system of echo sounding was devised to meet a definite requirement which could not be met by any system then in existence. (2) The requirement involved the production of an echo depth-sounding apparatus to give a continuous record of the depth of water beneath a survey motor-boat of draught about 2 ft., travelling at full speed. A depth range of 0 to 200 ft., with an accuracy of about 1 ft., was specified. The first attempts were made with a modified form of the Admiralty pattern depth-sounder of the sonic type. The modified apparatus gave promise in a large tank at the Admiralty Research Laboratory but proved less satisfactory when tested at sea because of extraneous noises due to engine, propeller, and splashing water, which almost completely masked the relatively weak echo from the sea-bed. Furthermore, a serious practical difficulty arose in connection with the screening of the receiver from the transmitter. This was due to the fact that the wavelength in water of the low-frequency sound was comparable with the dimensions and draught of the boat, an unduly large proportion of the emitted sound consequently reaching the receiver by diffraction. These difficulties are inherent in all low-frequency systems and it was therefore considered preferable to avoid them by the use of a high-frequency system rather than to attempt to evolve expedients for overcoming them.

II. — DESCRIPTION OF THE NEW SYSTEM.

After experimenting with various types of high-frequency sound resources suitable for use under water it was finally decided to employ a principle which had hitherto found little practical application, viz. magnetostriction. The adoption of this principle arose out of some preliminary experiments dating from 1925 carried out in H. M. S. *Vernon* by Dr. E. P. HARRISON, who also collaborated with the authors in the early stages of development of the magnetostriction oscillator. The detailed design and construction of high-frequency magnetostriction transmitters and receivers will receive attention later in the paper, but for the present we shall consider only the general application to depth sounding.

The general arrangement is illustrated diagrammatically in Fig. 1. Two magnetostriction oscillators, a transmitter and a receiver, are mounted side by side in water-filled tanks and fitted in a chosen position in the motor-boat. The transmitter is excited into resonant vibration at regular intervals of time, depending on the range of depth to be recorded. These sound impulses are timed by means of suitable motor-driven contacts which synchronise with the traverses of the recording point across the record. The sound impulse may be either a damped train of high-frequency oscillations or a short signal of constant amplitude obtained from a convenient source of alternating current. The short train of high-frequency sound waves is directed vertically downwards to the sea-bed, whence it is reflected back to the magnetostriction receiver. Here the high-frequency pressure fluctuations are converted into corresponding alternating currents. These currents are amplified, rectified, and passed through the recorder. The latter is driven by the motor which controls the transmitting contacts, and the recording point is so arranged that its zero position on the record coincides with the instant of transmission of the sound impulse. While the sound impulse is travelling from the transmitter to the receiver via the sea-bed the recording point has travelled a corresponding distance from left to right of the paper. Various types of recorders have been used but a chemical recorder has hitherto proved most satisfactory, especially at the relatively high speeds of recording required in very shallow water. In the chemical recorder a small electrical current produces a stain on a chemically treated paper. Two such stains are, in general, produced at each traverse of the recording point, the first at the instant of transmission (the zero) and the second on the arrival of the echo. As the paper is slowly fed forward in a direction at right angles to the traversing point, two stained bands are obtained, one of which represents the zero or sea surface whilst the other represents the sea-bed. A continuous record is thus obtained of the contour of the sea-bed as the ship proceeds on its course. The width of the zero band is determined by the sound reaching

(1) Capt. A. J. L. MURRAY *and* N. SHUTTLEWORTH, *British Patent N°* 329403.

(2) *The experiments began towards the end of* 1929.

the receiver either by diffraction or by transmission through the hull. The band is of appreciable width; it is, however, less intense than the echo band in very shallow water. In order to record very shallow depths it is therefore sufficient to reduce the sensitivity of the amplifier. Figures 15 and 17 (*a*) (See Plate 3) show records so obtained.

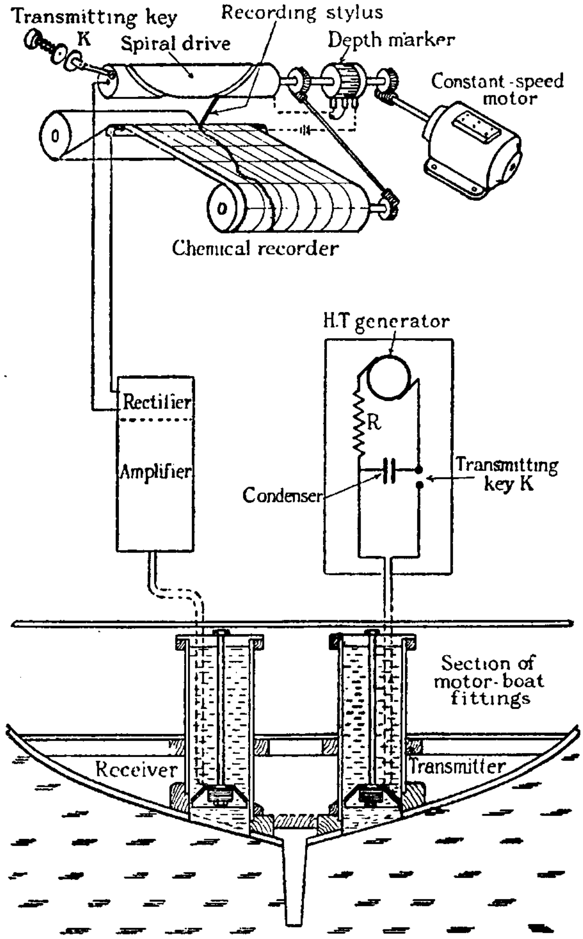


FIG. 1.
Magnetostriction echo depth-recorder. General arrangement.

An auxiliary commutator is used to produce a depth scale on the record, a series of equidistant dots representing known depth intervals being recorded at each traverse of the recording point.

As already stated, the apparatus was originally designed for recording depths from 0 to 200 ft., but the method has also proved satisfactory in depths exceeding 400 fathoms.

III. — THE MAGNETOSTRICTION OSCILLATOR — TRANSMITTER AND RECEIVER.

Some ferromagnetic materials possess the properties of changing their linear dimensions when subjected to a magnetic field (the JOULE effect) and conversely of changing their magnetic condition when mechanically strained (the VILLARI effect). These properties have formed the subject of research by numerous investigators (1) in a wide range of alloys, especially the alloys of iron, nickel and cobalt. A series of curves for

(1) *A bibliography is given in papers by* S. R. WILLIAMS (Journal of the Optical Society of America, 1927, *vol.* 14, *p.* 383), *and* L. W. MCKEEHAN (Journal of the Franklin Institute, 1926, *vol.* 202, *p.* 737).

various materials showing the fractional change of length dl/l with magnetic field is shown in Figure 2. The form of this curve varies from one material to another, and with the previous thermal and mechanical treatment. The curves in Fig. 2 show clearly that annealed nickel and cobalt steel give the largest magnetostriction effects within the limits of 0 to 100 gauss magnetizing field, that is, between the origin and the dotted line. For low values of H, soft annealed nickel is definitely superior to hard-rolled nickel.

A) *Choice of Material.*

The selection of a suitable material for a magnetostriction oscillator is to a large extent determined by considerations of a practical nature. A compromise between various conflicting factors is necessary, bearing in mind that the oscillators must be reproducible in large numbers on a commercial scale. The material selected must possess as far as possible the following qualities:

1°) Large magnetostrictive effects for relatively small magnetic fields.

2°) Simple and easily reproducible composition. (Alloys requiring exact proportions and exceptional heat treatment are therefore unsuitable, unless they possess a large compensation in (1) above).

3°) Good mechanical properties. The material must be available in thin sheet and stampings and in the form of thin-walled tubes.

4°) High resistance to corrosion when immersed for long periods in water.

Combining these desirable qualities, nickel of ordinary commercial purity appears to be the most suitable magnetostrictive material for the purpose; it is simple in composition and easy to anneal; it has good mechanical properties and can be readily obtained as thin sheets, tubes or stampings; and it has a high resistance to corrosion, remaining for long periods in water without sign of deterioration.

With regard to its magnetostrictive properties, nickel is, as we have seen in Fig. 2, one of the best materials obtainable. For small magnetizing fields it shows a large JOULE effect, a contraction of the order 30 parts per million being observed for fields up to 100 gauss. The rate of change of length with magnetization is very large for small values of H. The maximum peak value of alternating sinusoidal stress which can be usefully obtained from nickel with an upper limit of field strength of 50 gauss is of the order of 400 lb. per sq. in. It is of interest to note that the corresponding stress produced piezo-electrically in quartz by an applied potential of 2,000 volts per cm. is of the order of 4 lb. per sq. in.

Nickel has been chosen on these grounds for the magnetostriction oscillators described in this paper. Various alloys have been tried but as yet the results have not proved so satisfactory, for one or more of the reasons given above. In what follows, therefore, we shall be concerned with nickel magnetostriction oscillators.

B) *Design of Oscillators. — Cylindrical, Ring and Strip Types.*

Fig. 2 illustrates the small changes of length observed in magnetostrictive rods or wires when subjected to steady magnetizing fields. If a magnetized rod is subjected to the action of an alternating magnetic field parallel to its length, mechanical oscillations at the frequency of this alternating field are set up; when this frequency coincides with the natural frequency of the rod in longitudinal vibration, resonance occurs and a large increase in the amplitude of vibration results. Under these conditions of resonance the rod becomes more efficient as a source of sound. The phenomenon in this simple form is practically useless for the generation and reception of sound at high frequencies. In the first place, the eddy currents in the rod prevent the penetration of high-frequency alternating magnetic fluxes, and only a thin layer of the material on the outside of the rod is effective in producing vibrations. Again, the demagnetizing effect of the ends of short bars (of high longitudinal frequency) prevents the magnetic induction from attaining sufficiently high values. Consequently it is desirable that the magnetostrictive material should be constructed (*a*) of thin sheet or laminations, and (*b*) in the form of a closed magnetic circuit.

The first of these requirements appeared to present an almost insuperable difficulty. Thin laminae are not usually regarded as capable of resonant vibration at high frequencies. Experiments have shown, however, that such laminae, if not excessively thin, resonate reasonably well, the internal damping being small relative to that due to radiation damping when a pile of the laminae is immersed in water. Motional impedance measurements with such a pile of annular nickel stampings show a high degree of reson-

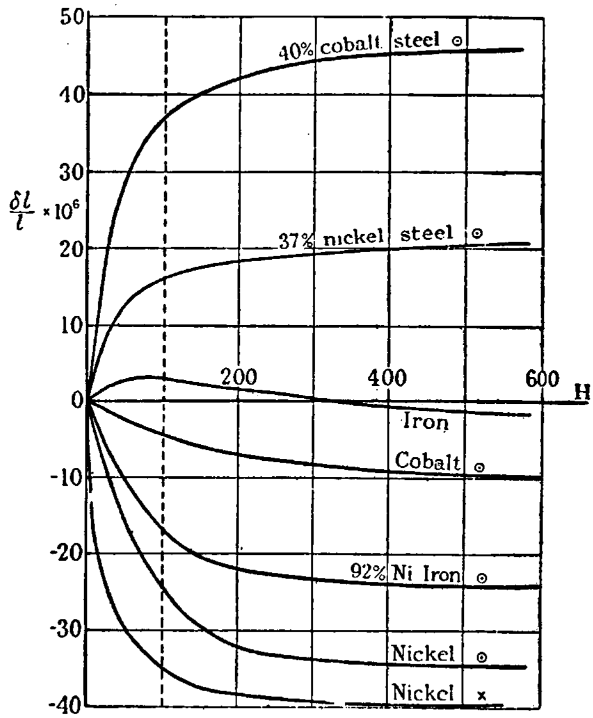


FIG. 2.

Magnetostriction in ferromagnetic materials.

⊙ ⊙ *Honda and Kido.* X X *Yosio Masiyama.*

ance for radial vibration in air. Similar measurements in water confirm that the internal mechanical damping of the laminae is small compared with the radiation damping ; the efficiency of conversion of electrical into mechanical energy is very good.

Various forms of these high-frequency oscillators have been constructed in accordance with the two principles mentioned above. It will be sufficient, however, if three of these are now described, all of which have given satisfactory service in echo sounding. In all cases the nickel is annealed at a temperature of approximately 1,000° C. To avoid excessive eddy currents the contiguous layers of nickel must be insulated from one another. This is done in numerous ways, two of which may be of interest. In the first of these the thin nickel sheet is oxidized by heating in contact with air in the furnace, either during or after the annealing process. This coats the annealed nickel with a thin film of greenish black oxide which serves as a very effective electrical insulator. In addition to the property of electrically insulating the nickel layers from one another, the thin film of oxide also serves as some protection of the nickel from corrosion when in contact with water. In the second method the annealed nickel is coated with a suitable insulating varnish, which may be allowed to dry previous to the assembly of the oscillator or which may be applied wet during the assembly. In the latter case thin paper or similar solid insulator is also interleaved between the layers of nickel.

(i) *Cylindrical Oscillators, Scroll Type ; Longitudinal vibration.* — An example of this type of oscillator, containing about 0.5 kg. of nickel, is illustrated in Figure 3. It is constructed by winding tightly on a mandrel long strips of nickel sheet and thin paper coated with cement. The hollow cylinder thus formed is consolidated by baking at an appropriate temperature. A load attached to one end serves to tune the oscillator to the desired frequency and to increase the area of vibrating surface in contact with the water. Such an oscillator is found to be sufficiently resonant mechanically and exhibits good magnetostrictive properties at supersonic frequencies. The only winding necessary consists of about 10 turns of low-resistance wire wound toroidally through the nickel

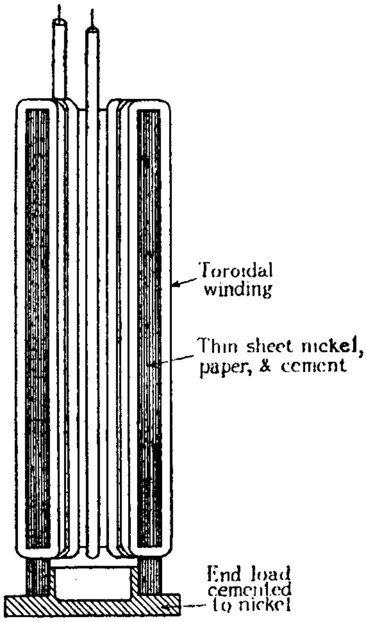


FIG. 3.

Cylindrical scroll-type oscillator.

cylinder as shown. Current through this winding produces circumferential magnetization which results in simultaneous changes in the length, diameter and thickness, of the nickel cylinder; the volume remains sensibly constant. Since it is desired to excite longitudinal resonant vibration the appropriate frequency of alternating current must be supplied. A converse process, involving the VILLARI effect, takes place when the oscillator is used as a receiver.

(ii) *Ring Oscillators ; Radial Vibration.* — This form of magnetostriction vibrator is a cylindrical pile of annular nickel rings (say 0.002 to 0.005 in. thick). These may be consolidated to form a solid resonant block by coating with a suitable insulating cement and baking under pressure. Alternatively, the laminations may be built up loosely into a pile so that they are free to vibrate individually and more or less independently. It is important, however, in the latter form of construction to obtain a reasonable uniformity between the individual laminations. This is achieved by stamping the annular rings from thin nickel sheet and "shuffling" a large number of such stampings to obtain an average in each oscillator and to avoid progressive errors in diameter due to the wear of the stamping tools. The fundamental frequency f of radial vibration of a circular annulus, of width small compared with the diameter, is given by

$$f = \frac{v}{\pi d}$$

where v is the velocity of sound in the material and d is the mean diameter of the annulus. For example, a ring of mean diameter 10 cm. resonates in this mode at a frequency $f = 15{,}900$ cycles per sec. A series of equidistant holes spaced round the periphery of the stampings accommodates the toroidal winding.

This arrangement leaves the sound-emitting surface, i. e. the edge of the stamping, free from obstruction. The circular magnetization produced by current in the toroidal winding results in a small change in the diameter of the magnetized ring, the amplitude of this reaching its maximum value when the frequency of the magnetizing current coincides with f, the fundamental radial frequency of the annulus.

An example of this form of vibrator is shown in Figure 4. It contains about 3 kg. of nickel stampings each 0,002 in. thick. The outer cylindrical surface constitutes the

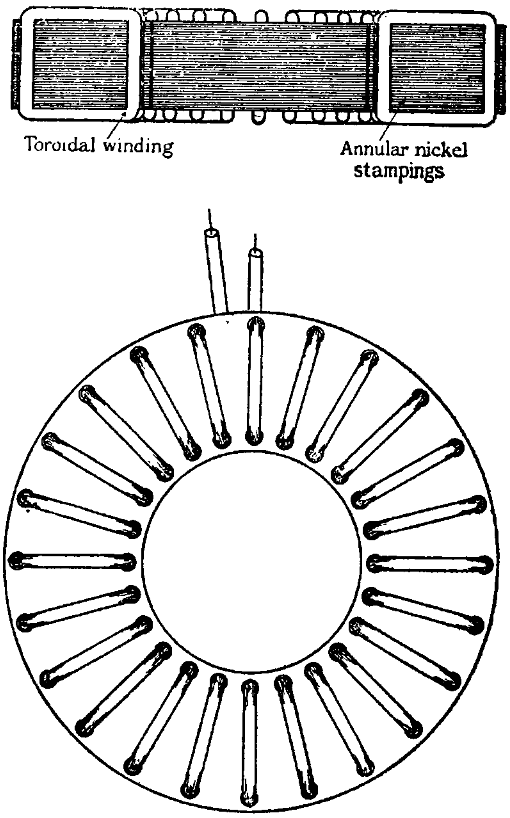


FIG. 4.
Ring-type Oscillator.

active sound-emitting surface in contact with the water. To prevent sound emission in opposite phase from the inner cylindrical face, the latter is covered with a layer of rubber mousse (1) or an equivalent air-filled space. The radiation damping of this form of oscillator may be controlled by varying the ratio of the surface area exposed to the water and the mass of nickel.

The mean diameter of the annulus is determined by the frequency required, while the radiation damping is controlled by the width of the ring. If a very large amount of damping is required with a given amount of nickel the cylindrical pile of stampings becomes relatively long and narrow, whereas for relatively small radiation damping the pile should be short and wide. The proportions shown in Fig. 4 have given good results in practice.

(iii) *Strip Oscillators ; Longitudinal Vibration.* — A third form of oscillator is shown in Fig. 5. The thin nickel stampings are rectangular in shape and consist essentially of two nickel strips connected by two tuning legs. The longitudinal members which connect the tuning legs may, with sufficient accuracy, be regarded as loads and the legs as springs. By varying the length and width of the legs and the depth of the end loads, any desired frequency can be obtained. These rectangular nickel stampings are annealed, oxidized, or coated, in a similar manner to the circular stampings. They are

(1) *Rubber mousse or expanded rubber froth is composed of small, watertight air cells.*

insulated from each other and are mounted to form a rectangular block of the required size. The magnetizing coils are wound around the tuning legs, which form part of the closed magnetic circuit. As in (*ii*) the edges of the stampings constitute the active sound-emitting surface in contact with the water, the opposite vibrating edges being

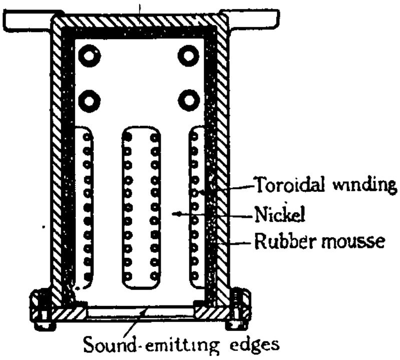
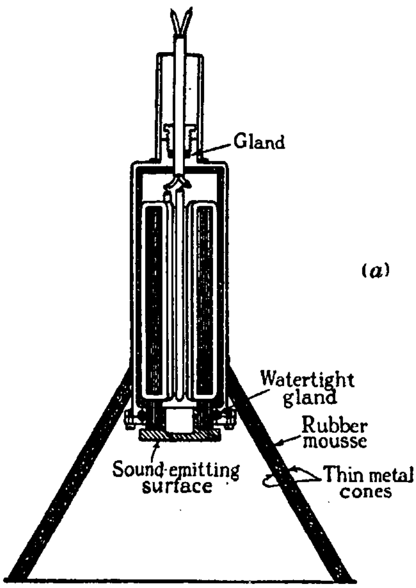


Fig. 5.
Section through strip oscillator.

screened as before by means of an air cavity, e. g. a layer of rubber mousse. The rectangular block of stampings is mounted in a suitable casing, not necessarily watertight, which may be lined with rubber mousse.



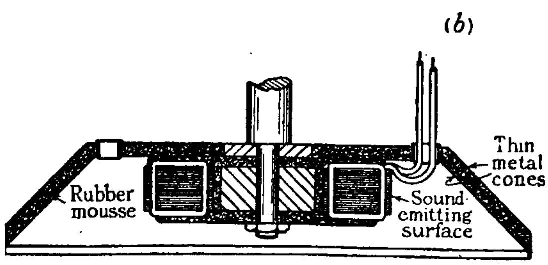


Fig. 6. $(a + b)$
Scroll and ring oscillators mounted in conical reflectors.

It should be observed that in most of these forms of magnetostriction oscillator it is possible to permit free access of water to the surfaces of the nickel and the associated windings.

c) *Air Reflectors. — Angle of Sound-beam.*

In order to obtain sufficient "directionality" in the magnetostriction transmitter and receiver, the oscillators just described, more particularly types (*i*) and (*ii*), must be mounted in some form of reflector. The semi-angle of the primary conical beam of sound emitted from a circular source of diameter D is given by

$$\theta = \text{arc sin } (1.22\ \lambda/D)$$

where λ is the wavelength of sound in the medium under consideration. Consequently at a particular frequency, e. g. 15 kilocycles per sec. (λ = 10 cm. in water) the angle of the primary beam of sound is fixed by the effective diameter of the source; analogous considerations apply also to the directional properties of the receiver. The sound energy from a source of diameter large compared with a wavelength of the sound emitted is confined to a relatively narrow cone. This is an advantage from the point of view of economy of sound energy; but in its practical application to echo sounding a very sharply directional transmitter and receiver may result in a loss of some of the echoes, particularly in a moving ship and over a rapidly shelving or undulating sea-bed. The choice of the angle of the beam is therefore a compromise.

With the cylindrical and ring type oscillators described above, an increase in effective diameter is obtained by means of a reflector, since the dimensions are too small to ensure sufficiently good inherent directional properties. Air is the best reflecting medium for use under water, a relatively thin layer producing total reflection. Two types of reflectors which have given good service are shown in Fig. 6. In both of these the reflector is formed by a pair of thin conical metal spinnings enclosing an air cavity. The double-walled enclosure is made watertight but to avoid failure of reflecting properties in case of leakage the cavity is filled with rubber mousse, which may be regarded as equivalent to air alone. The theoretical directional curve for type (*b*) reflector is shown in Fig. 7. The semi-angle of the primary cone of sound is about 20° with an oscillator of frequency 15 kilocycles per sec. The beam angle of the smaller type (*a*) is somewhat greater on account of its smaller diameter.

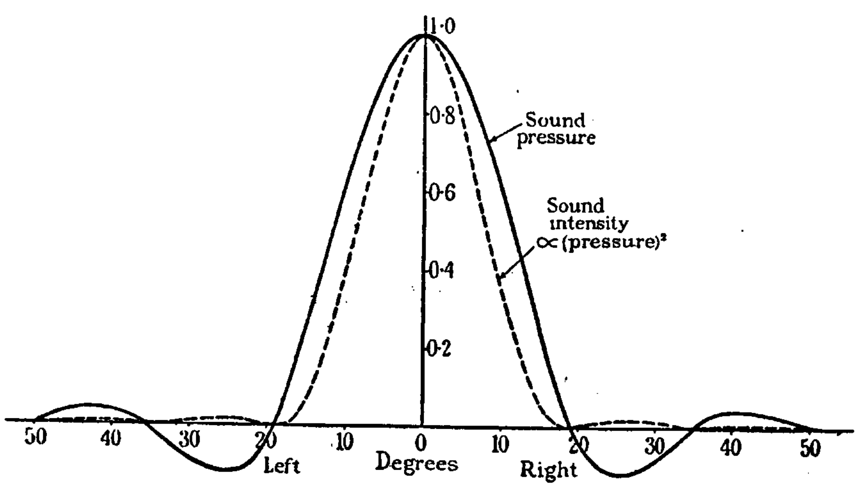


FIG. 7.

Theoretical sound-distribution curve of ring-type oscillator (15 kilocycles per sec.) with 12 in. dia. reflector.

IV. — THE TRANSMITTER. METHODS OF EXCITATION. THE RECEIVER.

As already mentioned, the magnetostriction oscillators described may be used either for generation of high-frequency sound energy or conversely for reception. One oscillator may be used both for the transmission of the sound and for the reception of the echoes by incorporating a suitable send-receive switch system in the apparatus whereby the magnetostriction oscillator is automatically switched from a transmitting circuit to a receiving circuit. It is more convenient, however, particularly in very shallow-water sets, to use independent transmitters and receivers, and in what follows we shall confine our attention to such arrangements.

Various methods have been used to excite resonant high-frequency vibration in the transmitter. Two of these which have given good results in practice are conveniently described as (*a*) damped-impulse transmission and (*b*) continuous-wave transmission.

(a) *Damped-Impulse Transmission.*

This method is illustrated in Figure 8. A condenser C is charged through a current-limiting resistance R from a supply voltage V, the key K being then in position 1. At a predetermined time the key switches over to position 2 and the condenser discharges through the low-resistance winding of the magnetostriction oscillator. This produces a heavily-damped high-frequency alternating current in the oscillator circuit. The frequency and amplitude of this current are given approximately by the usual relations between the capacitance, inductance, and resistance, of the circuit. In this method it is found that little advantage is gained by supplying the nickel with an additional steady magnetization. The optimum value of the capacitance C is that which tunes the transmitting circuit to a frequency half that of the mechanical resonance of the nickel oscillator. Under these conditions the inductance of the circuit varies with the instantaneous value of the current, and an average value must be taken as sufficiently accurate. The energy stored in the condenser and discharged through the winding of the magnetostriction oscillator at each transmission is

$$\frac{1}{2} CV^2 \text{ joules (if } C \text{ is measured in farads and } V \text{ in volts).}$$

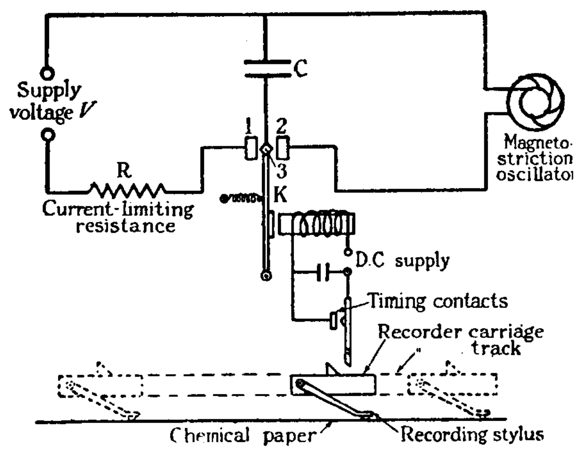


FIG. 8.

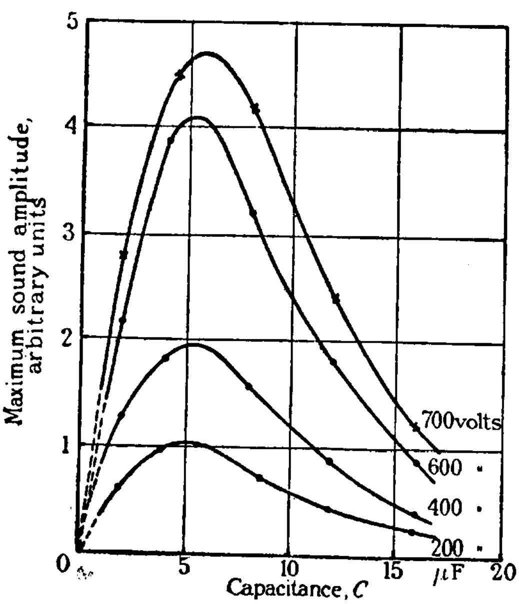
Damped-impulse transmission.

Sound output increases with increase of both C and V, more particularly the latter. As we have just seen, however, the optimum value of C is fixed by the frequency f and inductance L of the oscillator. By reducing the number of turns in the winding, thereby reducing the inductance, it is possible to increase C, but a practical limit is soon reached in this direction owing to losses in connecting cables. Transformers give some improvement, but the simple direct circuit shown has given very good results without such additions. The effect of varying the capacitance C and the voltage V is illustrated in Fig. 9. The ordinates represent in arbitrary units the peak value of sound amplitude observed in the water at 32 ft. from the transmitter, and the abscissae represent capacitances. The tuning effect produced by a capacitance of 5 or 6 *uF* is clearly shown. The increase of sound amplitude with increase of voltage is rather more rapid than the simple linear law which might have been anticipated. This is due to the fact that the relation between the magnetostriction strain and the applied magnetizing fields is not linear.

The effective resistance of the magnetostriction transmitter, deduced from oscillograph records, is of the order of 1 or 2 ohms only at frequencies in the neighbourhood of 15 kilocycles per sec., most of which is due to eddy-current and hysteresis loss in the nickel. When a condenser of 6 *uF* capacitance charged to 1,000 volts is discharged through such a low resistance, large instantaneous currents are developed.

Cathode-ray oscillograph records, examples of which are reproduced in Figure 10 (Plate 1), confirm this conclusion, peak currents of several hundred amperes being observed. The records show the complex nature of the wave-form and the rapid decay of the oscillations. Practically the whole of the energy stored in the condenser is discharged during the first cycle. The importance of reducing the effective resistance of the circuit will thus be realized. This has been achieved as far as practicable by the use of thin annealed nickel stampings and a special type of transmitting key. One form of the latter is shown in Fig. 11; copper contacts of large area discharge the condenser through the winding of the magnetostriction oscillator. These contacts (about 1 in. diameter) are arranged to meet with parallel faces at a fairly high speed (about 5 ft. per sec.). In this way the resistance is kept down to a low value and sparking is very slight even at 1,000 volts. When it is desired to fit the magnetostriction transmitter on the hull of a large ship, with the control switch-board and recorder at some remote point, the resistance of leads is minimized by mounting an electromagnetic key (with condenser) as near as possible to the magnetostriction transmitter. This arrangement is then operated from small auxiliary timing contacts mounted on the depth recorder as shown in Fig. 8. The recorder carriage closes these contacts in its travel from right to left of the diagram, but not in the reverse direction.

The form of the electrical oscillations in the receiving circuit is shown in the cathode-ray oscillograph records (series B) in Fig. 10. When a tuned magnetostriction



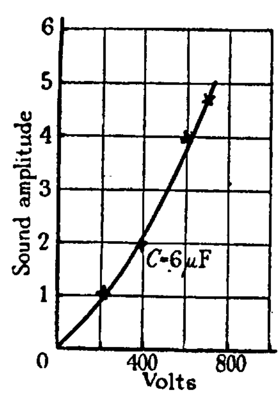


Fig. 9.

Variation of sound amplitude with capacitance and voltage. (Ring oscillator, 15 kilocycles per sec., in 12 in. dia. reflector).

oscillator is used in conjunction with a tuned circuit, the peak value of received current is attained after 0.001 sec. approximately, which corresponds to an echo range of 2 ½ ft.

(b) *Continuous-Wave Transmission.*

A useful alternative to the condenser-discharge method of exciting the magnetostriction transmitter, which should prove valuable in extending the magnetostriction method of echo sounding to greater depths, may conveniently be described as the continuous-wave method. The principle is illustrated in Fig. 12. The short, heavily-damped oscillatory current impulse of the condenser discharge is replaced by a short "dot" (lasting, say, 0.02 sec.) of alternating current of relatively constant amplitude. In this case it is desirable to magnetize the nickel oscillator by means of an auxiliary d. c. circuit containing a choke coil as shown in Fig. 12. The superposed alternating current adjusted to the resonant frequency of the magnetostriction transmitter may be obtained from a valve oscillator (as illustrated in Figure 12).

The transmitting key now connects the a. c. supply for the required short time-interval, and a corresponding short train of high-frequency sound of approximately uniform amplitude is emitted by the transmitter.

(c) *The Receiver.*

As already stated, magnetostriction receivers are identical in construction with transmitters. They are built up of the same thin nickel stampings wound with a few turns of low-resistance insulated wire and are mounted in similar air-filled reflectors to obtain the desired directional properties. Since both transmitter and receiver are highly directional, they may be mounted side by side in the bottom of a ship without risk of serious interference by direct sound. Both transmitter and receiver face the sea bottom, and the receiver is consequently sensitive to high-frequency sound approaching from this direction only.

The sensitiveness of the receiver is dependent on its initial state of magnetization. Since the magnetic circuit through the nickel is closed, any residual magnetization may be regarded as "permanent". Consequently when once the circular magnetization of the

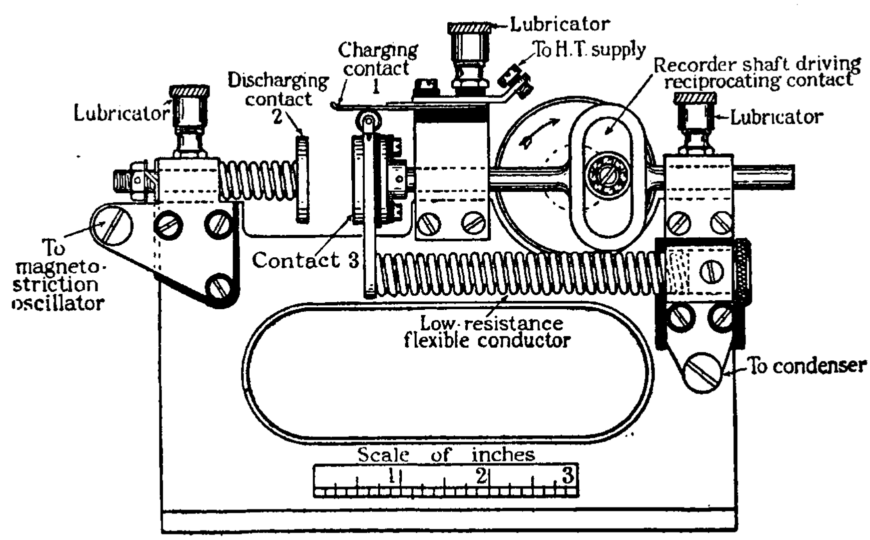


Fig. 11.—Details of transmitting switch.

stampings has been produced by means of a direct current through the windings, further use of the current is unnecessary. The process of magnetization is carried out by passing a large current momentarily through the toroidal winding of the magnetostriction receiver. When once magnetized in this way the receiver retains its sensitiveness. The frequency of the receiver must of course be the same as that of the transmitter and it is therefore usual to assemble both from the same batch of nickel stampings.

V. — THE AMPLIFIER-RECTIFIER.

The small electromotive forces developed in the magnetostriction receiver are amplified by means of a step-up transformer with tuned secondary winding. The output from this tuned circuit is applied to the grid of the first valve of an amplifier. In these days the choice of amplifier is extensive and it is unnecessary to go into much detail. A suitable pattern of resistance-capacitance-coupled amplifier is illustrated in Figure 13. This type has three or four stages of amplification with a step-down output transformer and a full-wave type of copper-oxide rectifier.

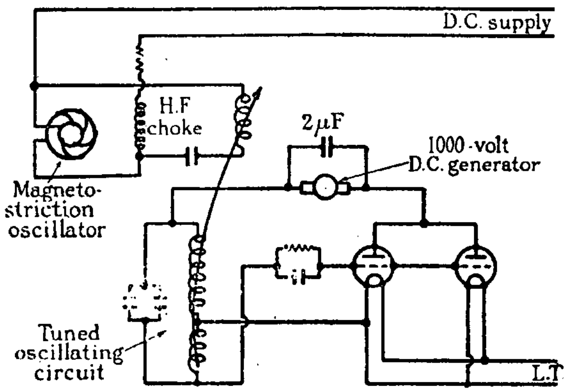


FIG. 12.—Continuous-wave transmission

In echo depth-recorder sets for very shallow water the small generator used to charge the transmitting condenser also supplies current to the plate circuits of the valve amplifier. The direct current from the copper-oxide rectifier passes through the platinum recording stylus (positive) and the aluminium recording bar (negative) of the chemical recorder.

A thyratron valve has also been used with success as a relay interposed between the amplifier and the recorder. This arrangement is most advantageous when the chemical recorder is replaced by some other type, e. g. an inked-thread recorder.

VI. — THE RECORDER.

Experiments have been made with various types of recorder, but the one giving most satisfactory results is that in which small electrical currents produce a stain on a chemically prepared paper. A large selection of chemicals is available for such a purpose, one of the best being a solution of potassium iodide and starch. The paper soaked in this solution is used in a slightly moist condition. The stain produced by the current has a brownish-purple colour which changes to a definite brown on drying.

The form of recorder preferred for short-range echo detection is shown in Fig. 14 (Plate 2) and diagrammatically in Fig. 1. This recorder is driven from a small electric motor fitted with a governor to ensure constancy of speed. A pair of timing contacts are provided which may be used either as the actual transmitting contacts or as auxiliary contacts for the operation of a separate electromagnetic transmitting key. The recording stylus is carried on a traveller which engages with a helical groove cut in the surface of a cylinder geared to the main drive. Rotation of the cylinder produces a to-and-fro motion of the traveller across the paper. A simple cam in the traveller brings the recording stylus into contact with the paper in the left-to-right direction and lifts it off on the return journey. A roll of unsized paper is wound slowly past a wick, which wets it with chemical solution, or with water if the paper has been previously impregnated with chemicals. It then passes over a bevelled bar where the record is made, and thence to a collecting spool. The instant of transmission of the sound impulse is synchronized with the zero position of the stylus as it begins its traverse across the paper; at this instant a stain is produced on the record. While the high-frequency sound impulse travels from the transmitter to the receiver via the sea-bed the recording stylus traverses the paper strip. At the instant of arrival of the echo a second stain is produced on the paper strip. This procedure, repeated at regular intervals, results in two stained bands on the record, the first of which represents the instant of transmission and the second the instant of arrival of the echo. The distance apart of these bands is proportional to the depth of water through which the high-frequency sound has travelled. The scale of depth indicated by the record depends, of course, on the speed of traverse of the stylus across the paper. For example, the width of the actual record in very shallow-water sets is approximately 5 in. per 200 ft. of depth since the stylus crosses the record in 1/12th sec. approximately. In a 200-fathom recorder the speed is one-sixth of this. A variable-speed drive might of course be

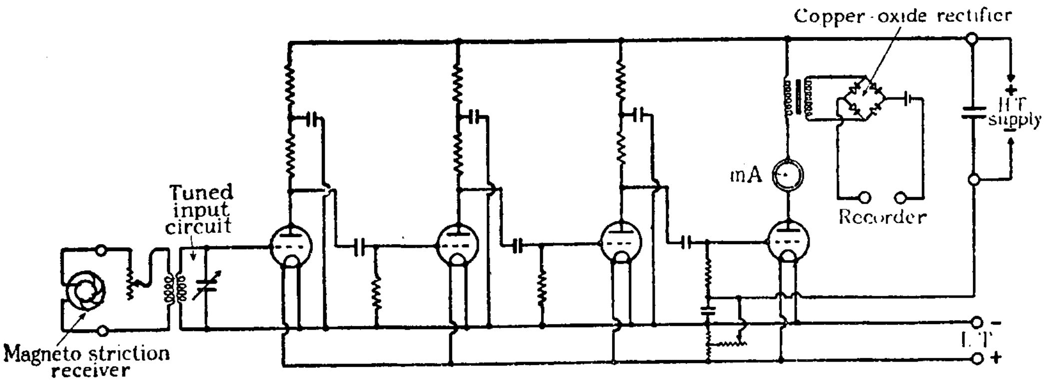


FIG. 13.

Resistance-Capacitance-coupled amplifier

incorporated to vary the speed of traverse of the stylus, so that the same paper width would correspond to any required range of depth to be recorded. Provision is made in some recorders for a total range of depth of 0 to 420 fathoms. The recording stylus crosses the paper in a time corresponding to 70 fathoms, and by advancing the instant of transmission in steps equivalent to 50 fathoms the series of overlapping ranges 0-70, 50-120, 100-170,........... 350-420 fathoms, is obtained. This expedient increases the effective width of the record by 6 times (1). In another experimental recorder the initial depth-range, determined by the width of paper, is 0 to 240 fathoms with provision for a zero advance of 200 fathoms, giving a maximum recordable depth of 440 fathoms.

An additional commutator has been introduced which causes the recording stylus to make a series of dots on the paper at equal intervals of depth — every 10 or 20 ft. in the very shallow-depth recorder and every 10 or 20 fathoms in the deeper-water sets. The dots form a series of equidistant lines on the record and provide a very convenient scale for reading the depth. As the depth scale is dependent for its accuracy on the speed of the stylus across the paper, it is important that this speed should be maintained constant. The driving motor is therefore provided with a reliable governor to control the speed within ½ per cent. A resonant steel-reed vibrator is mounted on the base of the recorder to indicate that the machine is running at the correct speed.

In some recorders designed specially for hydrographical surveying, provision is made for recording and numbering "fixes" to correlate the recorded depths with cross-bearings on shore marks. At the instant of making a fix, a line is produced on the record by momentarily short-circuiting the depth-marking commutator. Each line is subsequently identified by a serial number printed near the edge of the record (see, for example, Fig. 15 on Plate 3).

VII. — TESTS IN LABORATORY TANK.

To examine the behaviour of the assembled apparatus, the magnetostriction transmitter and receiver were mounted side by side with their axes horizontal at a depth of about 3 ft. in the laboratory tank. The tank is 15 ft. wide, 10 ft. deep, and 85 ft. long. Regarding the end of the tank as corresponding to the sea-bed, a range of depth of approximately 80 ft. is available. Actually, the total effective range of depth is much greater than this, for the low-speed recorders show a series of multiple echoes spaced 85 echo-feet apart.

(1) J. G. GRACE *and* F. L. ANTHONY, *British Patent* N° 370051/32.

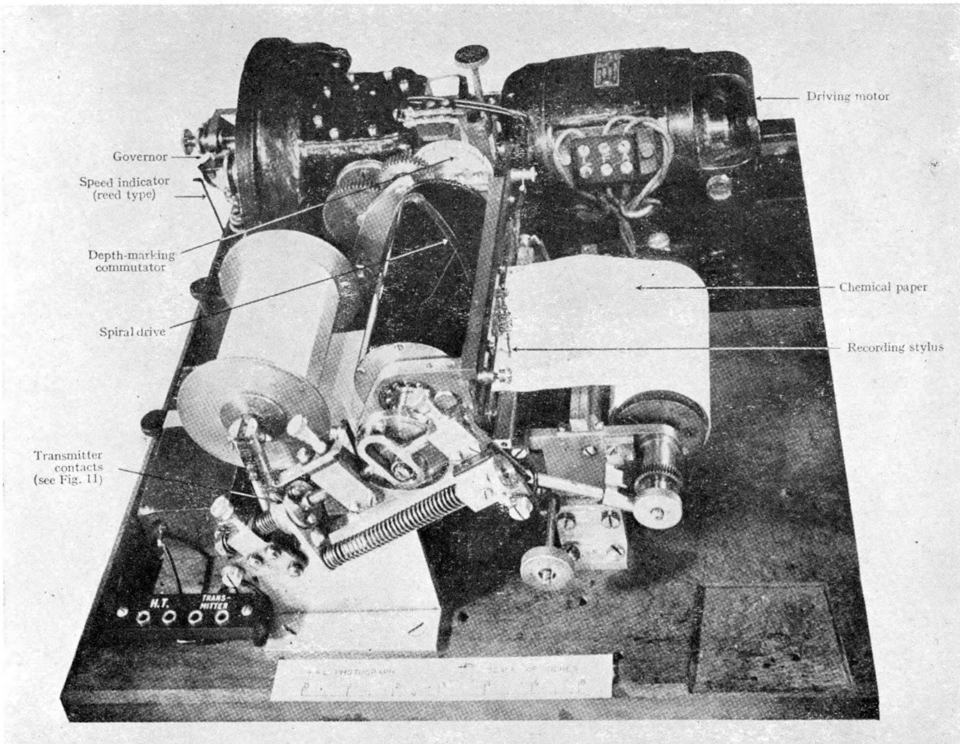


FIG. 14.—Recorder.

FIG. 14

Enregistreur.

Recorder.

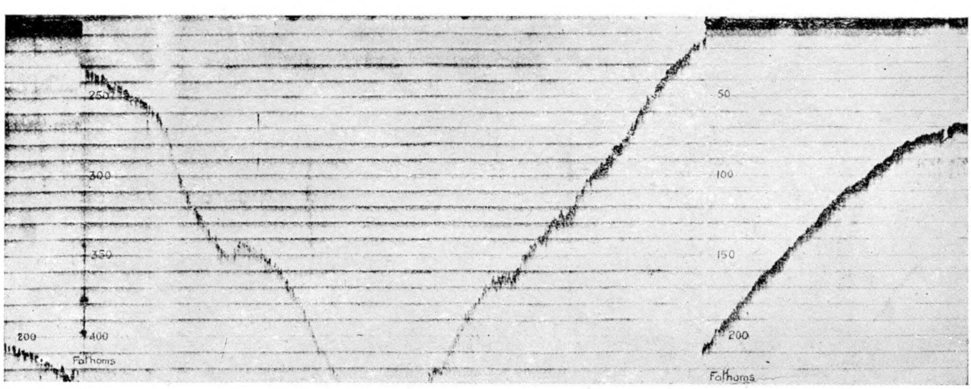


FIG. 20

Oscillateurs annulaires (intérieurs). Emission par impulsion amortie. (Vitesse du navire 10 nœuds ; vitesse du papier 0,2 pouce (5 mm.) par minute).

Ring oscillators (inboard). Damped-impulse transmission. (Ship speed 10 knots ; paper speed 0.2 in. per min.).

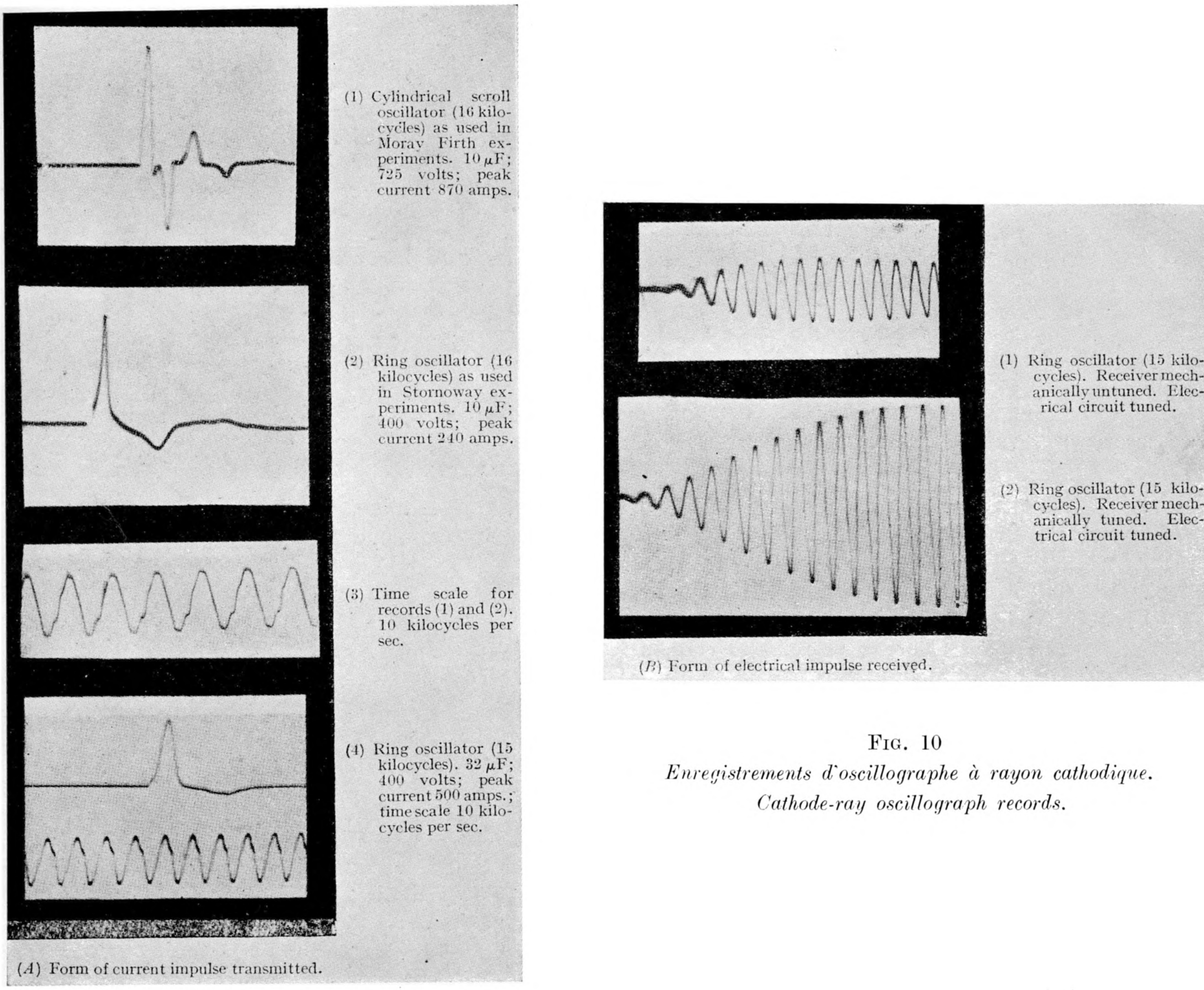


FIG. 10

Enregistrements d'oscillographe à rayon cathodique.

Cathode-ray oscillograph records.

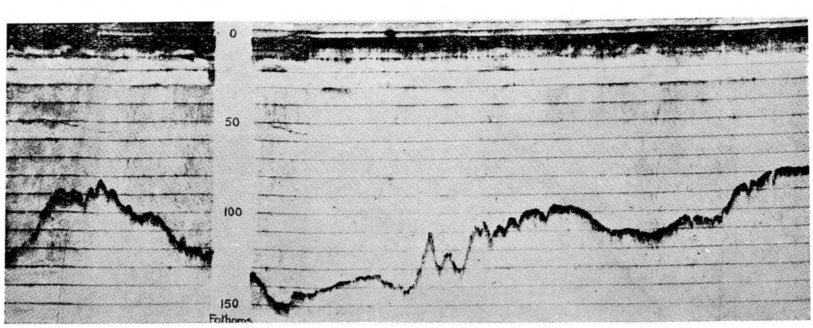


FIG. 19

Oscillateurs annulaires (intérieurs). Emission par impulsion amortie. (Vitesse du navire 10 nœuds ; vitesse du papier 0,2 pouce (5 mm.) par minute).

Ring oscillators (inboard). Damped-impulse transmission. (Ship speed 10 knots ; paper speed 0.2 in. per min).

Figure 15 is a typical record showing the first and second echoes. It was obtained with the recorder for shallow water (range up to 200 ft.) with reduced sensitivity. The equivalent variation of depth was obtained by moving the transmitter and receiver along the tank on a travelling platform. The sharpness of the first recorded echo permits of an accuracy of ± 1 ft. in the estimation of depth. Fix or cross-bearing lines with their corresponding numbers are shown on this record. The overall sensitivity of magnetostriction depth recorders was sometimes measured by counting the number of successive echoes which could be recorded. The relative strengths of successive echoes were measured in two ways, (*a*) by adding resistance R to the circuit of the receiver until any required echo was only just visible on the record, and (*b*) by measuring the electromotive force E developed in the receiver by means of the signal-strength meter described by B. S. Smith and F. D. Smith. This instrument produces known alternating electromotive forces which can be matched on the record with the echo.

The results of such a series of measurements by methods (*a*) and (*b*) are plotted in Fig. 16, which shows clearly the regular logarithmic decrease of echo strength in a succession of 9 or 10 echoes in the A. R. L. tank. Both methods of observation indicate that the electromotive force, proportional to sound amplitude, produced by each echo is 2.6 times that of the one following. A gain of an additional echo therefore represents a very marked improvement.

The cathode-ray oscillograph has been used extensively in making comparisons of magnetostriction transmitters and receivers. Reference has already been made to an investigation of the wave-form of transmitter current-impulse and received sound-impulse. The following problems, all bearing directly on the performance and efficiency of the apparatus, have also been examined with the help of the oscillograph.

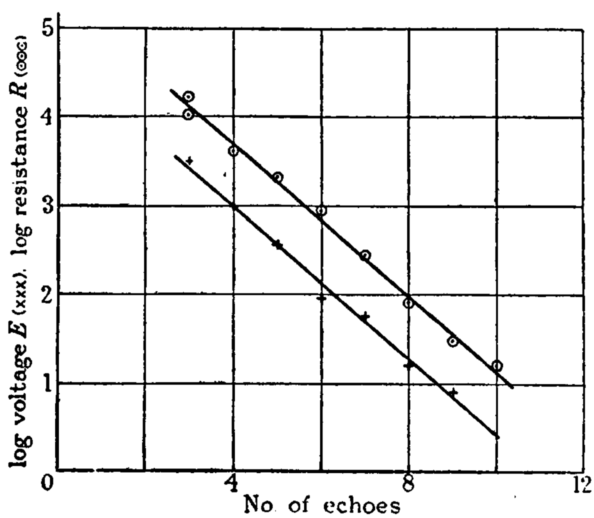


Fig. 16.

No. of echoes.

1). Variations of capacitance and voltage in the transmitter circuit.

2). Modifications in the size and shape of reflectors.

3). Variations of water-damping in transmitters and receivers.

4). Transmission of sound through steel plates of various thicknesses.

5). Variation of the distance between the magnetostriction oscillator and the steel plate (ship's hull).

6). Directional properties of various reflectors and oscillators.

Such measurements with cathode-ray oscillograph and signal-strength meters have resulted in a considerable improvement in the apparatus. In the first experiments only one end reflection was recorded in the tank; it is now possible to obtain 11 or 12 successive echoes.

VIII. — EXPERIMENTS AT SEA.

Sheerness Experiments.

The apparatus in its original form was first tested in a survey motor-boat at Sheerness in February, 1930. Good records were at once obtained of the contour of the sea-bed with the motor-boat running at full speed (8 knots) in choppy water. The depths available and actually recorded varied from 0 to 95 ft. and agreed well with soundings taken by lead line. In the latter case reliable measurements were possible only when the bottom was nearly flat and the boat was stopped. Specimens of early records are shown in Fig. 17 (Plate 3). The first record represents a run at 8 knots across the main channel from a shallow boat-camber on one side to mud flats on the other. In the second record, which crosses the channel at its deepest part (92 ft.) a second echo is recorded. This second echo is visible on the record at 200 ft., the maximum depth for which the recorder was designed. As a result of these experiments a number of modifications were made in the apparatus. In an earlier form of recorder the platinum recording stylus was driven by a chain passing over two sprocket wheels. This arrangement worked fairly well, but vibration of the chain and backlash in the links at these high speeds resulted in a certain amount of blurring of the record. It was replaced by a spiral drive (see Figure 14) which runs very smoothly and gives a record relatively free from irregularities. In these early experiments the transmitter and receiver were fitted in a frame on the gunwale of the boat and held at a depth of 18 in. below the water-line. This temporary outboard mounting was replaced by a more permanent inboard arrangement. Two openings, 8 in, square, were cut in the bottom of the boat and wooden tanks constructed above them, the upper edge of these tanks being 6 in. above the water-line. This arrangement facilitated the removal of either the receiver or transmitter for inspection or adjustment without the necessity of docking the boat. A few runs were made with the hull openings uncovered, but it was soon found that air bubbles and seaweed collected in the transmitter and receiver cones and ultimately cut off the sound completely. The holes were subsequently covered with copper sheet of the same thickness as that used to sheathe the bottom of the boat. Good records were obtained at full speed even in bad weather. No trouble was experienced from extraneous noises, such as engine, propeller, or water noise, nor from the generator charging the 21-volt accumulators which supplied the whole system, including the amplifier, with power.

Fraserburgh Experiments — H. M. S. Fitzroy.

Further tests of the depth-recorder for shallow water (survey motor-boat type) were made in the Moray Firth, about 10 miles due north of Fraserburgh. The recorder was then tested in deeper water up to the limit of its range, viz. 200 ft. In these experiments the cylindrical scroll-type magnetostriction oscillators of frequency 16,000 cycles per sec. were used with the damped-impulse (condenser discharge) method of transmission. A condenser of $8\,uF$ capacitance was found to give the best results in the transmitter circuit. With a charging voltage of 250 this condenser supplied 0.25 joule per impulse, whilst at 400 volts the energy per impulse was increased to 0.64 joule. The records in the shallow-depth range 0 to 200 ft. were made with a recording speed of 4 ft. per sec. and a paper speed of 1 in. per min. approximately. Under these conditions good records were obtainable up to a depth of 120 ft. with a transmitting voltage of 150, and up to 180 or 200 ft. at 250 volts. Increase of transmitting voltage to 350 or 400 ensures greater reliability near the maximum depth. During these experiments the sea was rather lively; the waves were several feet high with "white horses", and the boat rolled and pitched considerably. In spite of this the bottom contour was clearly recorded up to the limit required, the echoes being quite strong at 30 fathoms. The record was not quite continuous; this was due to the violent motion of the boat and to masses of air bubbles which cut off the sound intermittently at both transmission and reception. A similar record with the echo depth gear arranged outboard from H. M. Survey Ship *Fitzroy* was almost entirely free from discontinuities. The improvement was undoubtedly due to the relative freedom from air bubbles and the greater steadiness of the larger vessel.

By reducing the recording speed to one-sixth, i. e. 8 in. per sec., the depth scale was converted from feet to fathoms. At this speed depths up to 120 fathoms, the maximum available near Fraserburgh, were clearly recorded.

Since that time improvements have been made by increasing the sound output and general efficiency of the apparatus to ascertain whether the depth recorder can be used, without serious modification, in greater depths.

Stornoway Experiments. — H. M. S. Flinders.

With this object in view a further series of tests were made in H. M. Survey Ship *Flinders* in water shelving from 16 fathoms, near Stornoway, to 1,000 fathoms, north-west of the Isle of Lewis. Ring-type magnetostriction oscillators, resonant at 15 kilo-cycles per sec. and fitted with 12 in. diameter reflectors, were mounted side by side in tanks welded to the side of H. M. Survey Ship *Flinders*. One of these tanks is shown in Figure 18. The high-frequency sound impulse and the returning echo therefore pass through the water of this tank and the steel hull, which in H. M. S. *Flinders* is 3/8 in. thick. Means were provided, as Fig. 18 shows, for varying the distance inside the tank between the magnetostriction oscillators and the hull. Experiments were also made with the same oscillators submerged to a depth of 10 ft. at the end of a strong pole lashed firmly to the side of the ship. A comparison of echo strengths obtained with the oscillators in this position and when mounted in the tanks, inside the ship, provides information relative to the loss of sensitivity due to the steel hull-plating.

The recorder and circuit controls were mounted in the wheelhouse, whilst the electromagnetic transmitting key and condensers were in a watertight box attached to a bulkhead near the inboard magnetostriction oscillators. The cable connecting the latter to the condensers was thus reduced to 3 or 4 yards only.

In this series of experiments a comparison was also made between the "damped impulse" and "continuous-wave" methods of transmission.

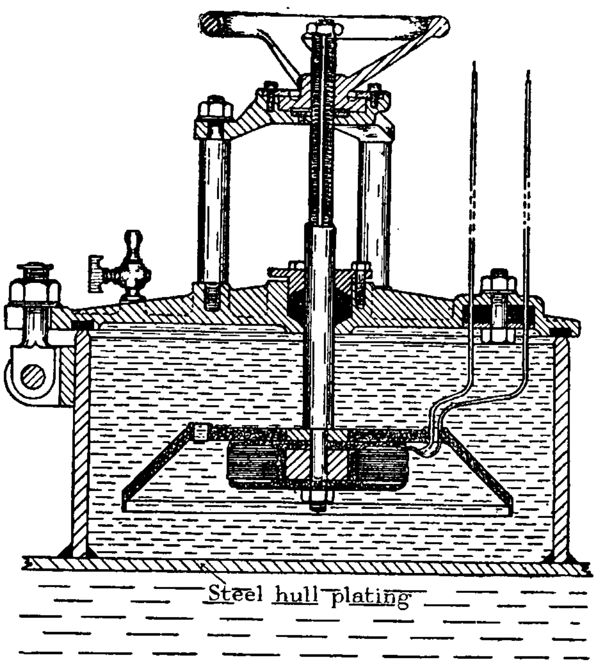


FIG. 18.

Magnetostriction oscillator (ring type) mounted in water-filled tank on hull of ship.

A preliminary test of the apparatus was made during the journey of H. M. S. *Flinders* from Exmouth to Lochinver in May, 1932. Inboard oscillators excited by the "damped impulse" (condenser discharge) method were used, the ship proceeding at its normal cruising speed of 10 knots. A specimen record, made in the North Channel (Beaufort Dyke) between Stranraer and Larne, is shown in Fig. 19 (Plate 1). The greatest depth encountered (150 fathoms) is clearly recorded.

Trials of the apparatus in deeper water commenced on the 20th June, 1932, when the recorder, equipped for recording ranges 0 to 240 and 200 to 440 fathoms, was started near Stornoway in a depth of 16 fathoms, continuing north-west of the Flannen Islands into 1,000 fathoms. The speed of the ship was normally 10 knots when inboard oscillators were used, but unavoidably reduced to 4 knots in the outboard tests on account of the risk of damage to cables. The weather was moderate during the tests, with a long swell and a somewhat choppy surface.

The records obtained, both "inboard" and "outboard", were good in depths up to the limit of the recorder, viz. 440 fathoms. Both the damped-impulse and the continuous-wave method gave good results at this depth. At the usual cruising speed of 10 knots no interference from ship or water noises was recorded. Specimen records are reproduced in Figs. 20 to 23 (Plates 2,3, and 4).

Damped-impulse method (transmitting and receiving through the 3/8 in. steel hull). (See Fig. 20). — In the shallower water, up to 200 fathoms, the transmitting voltage applied to the condensers was 450, raised to 900 or 1,000 volts in deeper water. As the depth approached 240 fathoms, corresponding to the full width of the paper, the zero was advanced 200 fathoms. The upper edge of the record is thereby changed from 0 to 200 fathoms and the maximum recordable depth increased from 240 to 440 fathoms. This is shown clearly on the record. In this run the ship was pitching in a long swell and moderate sea, the angle of heel was about 6°, and the double amplitude of roll was from 0° to 12°. The bottom is clearly recorded up to 440 fathoms. The fainter parts of the record have suffered considerably owing to storage of the records and in reproduction. On the return course the record is first made on the 200- to 440 fathom range, subsequently reducing to the 0 to 200 fathom range.

The same pair of oscillators was mounted outboard at a depth of 10 ft. below water near the corresponding inboard position. As before, the maximum depth was recorded. Echo-strength measurements indicated that the first bottom echo was 2 to 3 times as strong as that obtained at the same depth when the magnetostriction oscillators were mounted in the tanks, the sound in the latter case traversing the 3/8 in. steel hull twice. This indicates a loss of about 60 per cent in amplitude in the combined transmission and reception through the hull.

Continuous-wave transmission. — The transmitter was magnetized by a direct current of 10 amperes. An alternating current of 4 amperes at a frequency of 15 kilocycles per sec., was momentarily superposed on the direct current at each transmission. The records indicate that the duration of each transmission, and the corresponding echo, is greater than in the damped-impulse method. In Fig. 21 the range 200 to 440 fathoms is recorded. Near the left-hand edge of the record at the point marked *C* a deep cleft in the sea-bed appears at 350 fathoms, the bottom of which is not recorded. At 440 fathoms, at the point marked *W/T*, a number of lines cross the record. These are due to electrical interference produced by a radio transmitter a few feet away from the amplifier in the receiving current of the echo depth-recorder. On the return course of the ship, from deep to shallow water, a break is shown in the record at the point marked *S*, where measurements were made of the strength of the echo at a depth of 310 fathoms. The record continues in Fig. 22. The echo is very strong at every transmission, even the second echo at 120-240 fathoms being clearly recorded.

Measurements of echo strength made during the progress of these records showed the possibility of recording at still greater depths, and comparison of inboard and outboard measurements again indicated a total loss of about 60 per cent in amplitude for transmission and reception through 3/8 in. steel hull plating. This result confirmed previous observations of a similar character made in the laboratory tank at Teddington.

Messrs. Henry Hughes & Sons manufacture magnetostriction echo depth-recorders for the Admiralty and have also fitted them to a number of vessels of the trawler class. These vessels have usually 3/8 in. steel hulls sloping at a considerable angle from the keel. The high-frequency sound is incident on the steel plating at an angle of about 12° as it leaves and re-enters the ship after reflection from the bottom. Nevertheless very satisfactory records have been obtained even in rough weather with this type of vessel at full speed. A specimen record obtained by the Grimsby trawler *Glen Kidston* off the Norwegian coast near Bergen has kindly been supplied by Mr. Hughes and is shown in Fig. 23. The manner in which this record reveals the rugged "alpine" character of the sub-marine scenery is very striking. The scale of this record is 70 fathoms in depth,

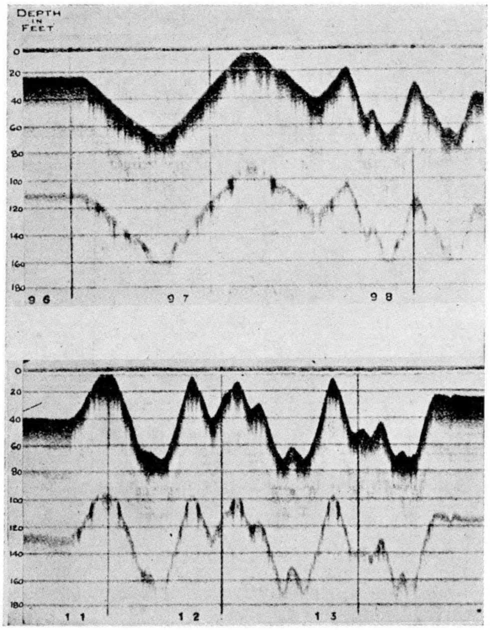


FIG. 15

Enregistrements obtenus dans le réservoir du laboratoire.

Tank records.

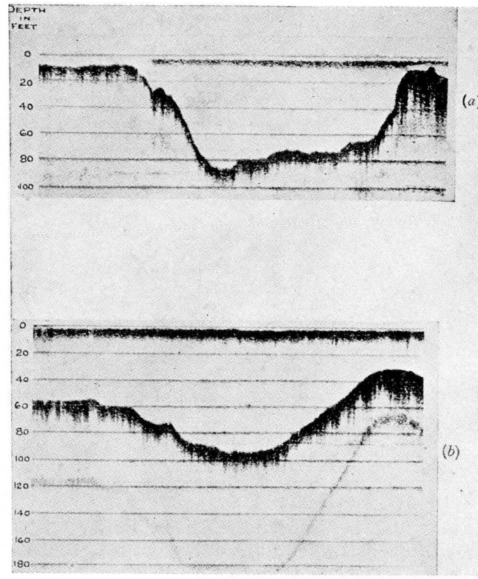


FIG. 17

Enregistrements provenant de la chaloupe à moteur de Sheerness. Vitesse du papier 1 pouce (25 mm.) par minute. Vitesse de l'embarcation 8 nœuds.

Sheerness motor-boat records. Paper speed 1 in. per min. Boat speed 8 knots.

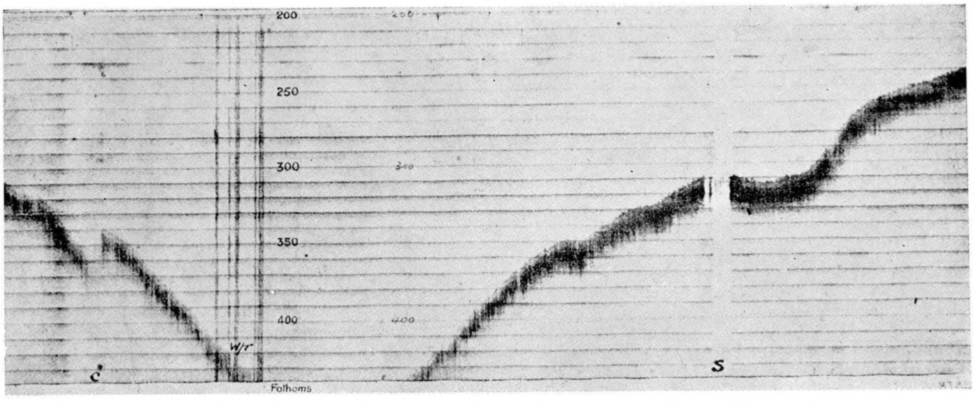


FIG. 21

Oscillateurs annulaires (extérieurs). Emission par onde entretenue. (Vitesse du navire 4 nœuds ; vitesse du papier 0,2 pouce (5 mm.) par minute).

Ring oscillators (outboard). Continuous-wave transmission. (Ship speed 4 knots ; paper speed 0.2 in. per min.).

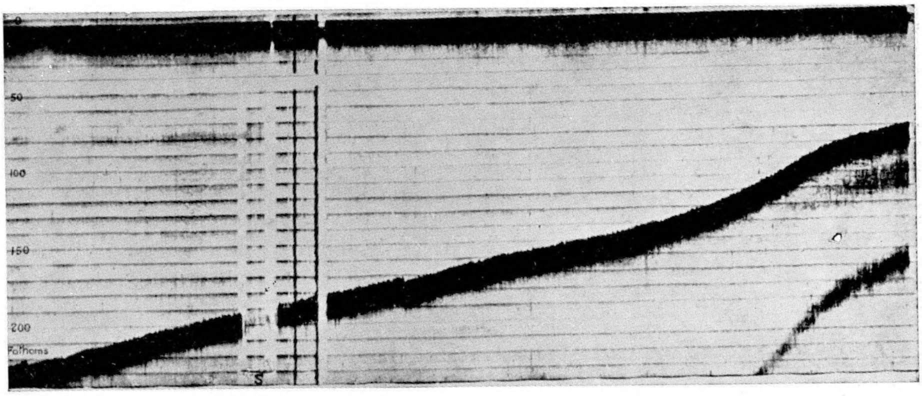


FIG. 22

Oscillateurs annulaires (extérieurs). Emission par onde entretenue. (Vitesse du navire 4 nœuds ; vitesse du papier 0,2 pouce (5 mm.) par minute).

Ring oscillators (outboard). Continuous-wave transmission. (Ship speed 4 knots ; paper speed 0.2 in. per min.).

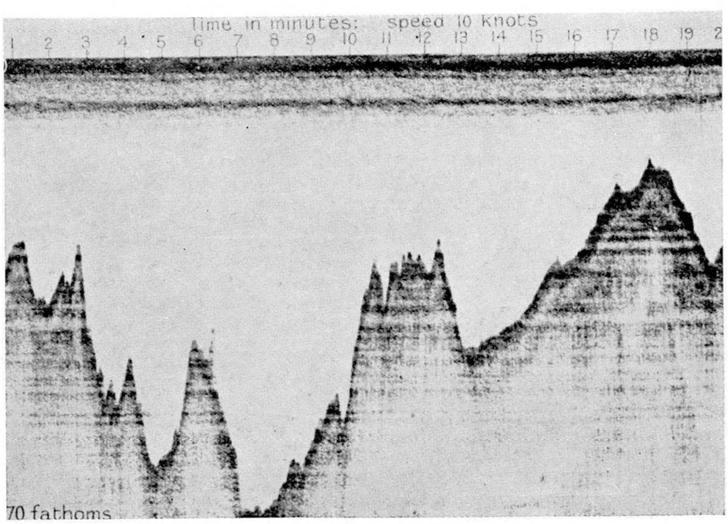


FIG. 23

Enregistrement pris par le chalutier de Grimsby Glen Kidston *près de Bergen. Emission par impulsion amortie.*

Record made by Grimsby trawler Glen Kidston *near Bergen. Damped-impulse transmission.*

and the time marks are made at intervals of 1 minute, the ship's speed being about 10 knots. The recorder on *Glen Kidston* is provided with an adjustment for advancing the instant of transmission in steps of 50 fathoms, and good records have been obtained up to 300 fathoms.

IX. — CONCLUSIONS.

a) *Requirements of Echo-sounding Apparatus. Ranges of Depth Sounding.*

The depth of the sea varies from 0 to 5,000 fathoms approximately, and the ideal depth recorder might be expected to cover the whole of this range with the same percentage accuracy at all depths.

The majority of ships, however, have little or no interest in deep-water (oceanic) soundings, but become more and more interested as the depth decreases. Ultimately, in very shallow water, a knowledge of the depth is of primary importance. A ship in very shallow or rapidly shoaling water, especially in insufficiently charted localities, must take frequent soundings. The importance of an echo depth-recorder therefore increases as the depth diminishes.

The depth range of the sea may conveniently be divided into three parts, (1) very shallow water, 0-30 fathoms, (2) water of medium depth, 30-200 fathoms, and (3) very deep (oceanic) water, 200-5,000 fathoms. Practically all ships which require soundings at all are concerned with the first of these ranges, 0-30 fathoms. Within this range the safety of the ship may be involved.

Of less, but still very great, importance is the range of navigational soundings extending up to 200 fathoms or so. Soundings in such depths are of value to the navigator who may use the record as a means of checking the position of the ship. Relatively few ships have any interest in depths beyond this range, say up to 5,000 fathoms.

The magnetostriction echo depth-recorder which has been described fulfils the more important requirements. It measures the depth to about 1 ft. in water of any depth from 0 to 30 fathoms or so, and in this respect is valuable to ships in dangerous or unknown shallow waters. This sensitiveness to depth in shallow water reveals in considerable detail the presence of wrecks or large rocks on the seabed. There are also important applications in survey work in river and harbour mouths, where the recorder may be used to control dredging operations and to check the thoroughness with which such operations are carried out. As regards navigation, experience has shown that the magnetostriction apparatus can give a good record of depth up to 400 fathoms or more, even when the sound is transmitted and received through a steel hull 3/8 in. thick. The records were not appreciably affected by the noises made by the machinery and motion of the ship at the cruising speed of the vessels fitted. Good results were obtained in bad weather conditions, the rolling and pitching of the ship having but little effect on the record.

b) *Choice of position of Echo-sounding Apparatus in ships (vessels of shallow draught).*

This depth recorder has an important advantage over certain types in the actual fitting in ships. In low-frequency systems it is necessary to choose two positions in the ship separated by about 50 ft., so that the direct sound from the transmitter is prevented by the hull from reaching the receiver. The position of the receiver is further restricted because of excessive parasitic noises such as noises from the engine room, pumps and auxiliary machinery, water noises and so on. These two conditions are sometimes difficult to fulfil. With the high-frequency magnetrostriction system, however, the transmitter and receiver require no special screening. They may be mounted side by side with no part of the hull separating them. The system is tuned both electrically and mechanically to a high frequency above the ordinary range of frequencies of the disturbing background of noise. Consequently the two main difficulties encountered in the low-frequency system do not arise. Whereas two positions in the ship must be chosen for the low-frequency type, only one is required for the high-frequency system. Furthermore, there is much greater freedom in the choice of the one position on account of the insensitiveness of the magnetostriction receiver to low-frequency noises. The importance of these considerations will be appreciated when it is realized that an error of judgment in the choice of positions of the transmitter and receiver in a ship may lead to complete failure.

When the draught of the ship is great the hull provides sufficient screening for the low-frequency system if the separation is of the order of 50 ft. or more. In ships of very shallow draught, however, it becomes difficult to provide efficient screening and the gear does not discriminate between the echo and the direct sound in shallow water. As already stated, the high-frequency gear requires no hull screening and in this respect should behave well in all types of craft. This property of the high-frequency system is a great asset.

c) *Simplicity and reliability.*

These two factors are of paramount importance in any gear which has to be used under average ship conditions. They become all the more important if the safe navigation of the ship depends on the depth recorder. Although the magnetostriction depth gear has been in use for a relatively short time only, it is possible already to form an estimate of its reliability and to correct some minor faults in its design. The most vulnerable element of any echo sounding gear is the part which is mounted in the water-filled tanks on the hull. These tanks are sometimes wellnigh inaccessible, and a defect in either the transmitter or the receiver is therefore liable to cause inconvenience and expense. In the magnetostriction system, both the transmitter and the receiver function even if flooded with water, so that the maintenance of watertightness is not vital. Provided insulation of good quality is used on the few turns (10 or 12) of wire which constitute the winding of the oscillator, no further attention should subsequently be required during the normal life of the cables. This feature is very important in gear which may be fitted in an almost inaccessible position in the ship.

d) *Directional Properties.*

The magnetostriction system may have any degree of "directionality" required. Hitherto it has been found satisfactory to use a conical beam of sound of semi-apical angle 20° or 30°. The comparative ease with which the receiver can be screened from the transmitter is due to the relatively short wavelength (about 4 in.) of the sound, and the directional properties of the conical reflectors.

Another advantage of the directional characteristic is that the soundings are taken directly, or almost directly, beneath the ship; little or no sound is transmitted sideways and the receiver is therefore insensitive to echoes from submerged cliffs or banks. In this respect also the directional beam is more discriminative of detail than non-directional types and is less liable to miss a submerged rock or a wreck. It has been urged against the directional system that it is affected by the roll of the ship and by steeply sloping banks. Whilst it is true that some echoes may be missed under such conditions, the case is not so bad as it first appears. It must be remembered that the sea-bed is not a mirror, and that sound of short wavelength is returned to the receiver from directions other than the simple reflecting angle. The trawler record shown in Fig. 23 is a sufficient answer. Under the worst conditions of rolling, however, the record of the bottom contour would appear as a dotted instead of a continuous line.

RECENT IMPROVEMENTS IN THE ULTRASONIC ECHO SOUNDING APPARATUS

by

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THE ULTRASONIC ECHO SOUNDER OF THE LINER NORMANDIE.

For reasons of safety all navigational instruments are doubled in their installation aboard the *Normandie.* There are two echo sounders, one sonic and one ultra-sonic. It might interest readers to learn some of the results obtained with the latter apparatus.

At first it was thought that the use of the sonic echo sounder might be accompanied by difficulties on board the *Normandie,* since, owing to the vessel's great speed it was feared the parasitic noises might cause serious interference in the reception.